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FLEXURAL BEHAVIOUR OF PRESTRESSED HOLLOW SLAB

V.S. Sreejith
M. Tech. Scholar, Department of Civil Engineering,
TKM College of Engineering, Kollam, Kerala, India

Dr. M. Sirajuddin
Professor, Department of Civil Engineering,
TKM College of Engineering, Kollam, Kerala, India

ABSTRACT

Precast construction techniques have gained huge popularity in the recent times due to rapid construction, excellent quality control, lesser site labour costs and more overall savings. In the current scenario, the most advanced type of prestressed construction is the manufacture of prestressed hollow core slab construction, which essentially consists of huge prestressed concrete panel units cast to the required slab dimensions. The construction is associated with the requirement of huge machinery for transportation, hoisting and placing operations. In the present study, a partially prestressed slab of dimensions 4000 mm × 600 mm × 120 mm was designed and cast. An RCC slab was also designed for comparing the behaviour of the prestressed hollow slab. The present study discussed about the flexural behaviour of pretensioned prestressed concrete hollow slab. The slab which was designed for this study consisted of three hollow cores, each having a diameter of three centimeters. A special mould was designed for casting, which was capable of withstanding huge prestressing forces. The hollow core provided within the specimen is an excellent method to improve material savings, thermal and sound insulation properties, besides being a provision for mechanical runs. The slab was cast and experimentally tested by subjecting it to uniformly distributed loads using sand bags to study the flexural behaviour of the slab.

Key words: Prestressed hollow slab, RCC slabs, flexural behaviour.

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1. INTRODUCTION

In India, precast construction is now gaining significant importance, particularly in urban areas. Most of the precast structures are prestressed concrete structures, in which internal stresses of a suitable magnitude and distribution are introduced so that the stresses resulting

from external loads are counteracted to a desired degree.A hollow core slab is a precast, prestressed concrete member with continuous voids extending the full length of the slab. Precast slabs are often used in prefabricated buildings as floor or roof deck systems. The units can be quickly assembled to form extensive floor slabs, by simply filling the joints between them and, eventually laying a topping. A hollow core slabs also have applications in wall panels, spandrel members and bridge deck units. As far as a slab is concerned, the flexural properties like deflection and bending moment is more important. The structure has been experimentally analysed, whether it can withstand the design load within the permissible deflection limit. In India use of precast structures instead of cast-in-situ is not that much established in case of building construction industry. In building constructions, majority of Indian industries are still following the traditional reinforced concrete construction methods to which the speed of construction is still lagging. This may be due to the limited research works available under the field of prestressed concrete construction in India. In view of the above observation, the study of precast structures is essential for the construction of durable structures, in short duration of time and with less cost.

2. LITERATURE REVIEW

Walraven *et al*. (1983) conducted an experimental study on bearing capacity of prestressed hollow core slabs. In this study two series of tests were carried out. In the first series, twelve tests were performed on single slabs subjected to line loads with variable load-span to depth ratios, and on double slabs, coupled by filling the longitudinal joint, subjected to eccentric line loads and concentrated loads. All these slabs failed in bending. In order to observe the various shear failure modes, a second series of tests were carried out. Thirty tests were carried out on slabs with varying cross section, depth and prestressing steel which were subjected to line loads with varying load span to depth ratios. These experiments yielded valuable information on the behaviour of prestressed hollow core slabs in various respects. From the studies the researcher came to a conclusion that, with regards to the behaviour of prestressed hollow core slabs, four different failure modes can be distinguished, two of the flexural and two of the shear type.

Aswad *et al*. (1992) conducted an experimental study in order to find out the behaviour of hollow core slabs subjected to edge loads. Three series of tests were conducted on prestressed hollow core slabs having various thicknesses. After these detailed studies the author identified two different modes of failures, local punching shear and shear-torsion near the end. In both cases the failure was sudden and brittle.

Prakash (2011) presented a paper based on precast concrete elements in construction and its emerging scenario in India. In this paper the author clearly described about the problems. The author suggested that the precast concrete offers solution to all the problems and setbacks faced by cast in place concretes. He pointed out that, rapid erection, quality assurance, possibilities of longer span structures and ease of construction as the advantages of precast structures. He also discussed about the market potential and technology of precast structures in detail.

Panfilov *et al*. (2015) conduct a theoretical and experimental study on deflections of reinforced concrete beams with allowance for discrete cracking. The theoretical part of the investigation is based on nonlinear deformation model, which takes into account nonlinear concrete and reinforcement behaviour and the discrete cracking. The experimental part of the investigation is based onprestressed reinforced concrete beams exposed to short duration uniform loading. As a result of the conducted theoretical and pilot researches, the author concluded that the value of a deflection of statically definable prestressed reinforced concrete beams with a pure bending zone exposed to short duration uniform loading, obtained by the

proprietary method showed the best convergence with experimental data. The conducted research confirms that the consideration of nonlinear properties of concrete and reinforcement influences the accuracy of deflections calculation.

3. MATERIAL PROPERTIESAND MIX PROPORTION

The properties of each material in a concrete mix were studied at this stage. Different tests were conducted for each material as specified by relevant IS codes. Ordinary portland cement, fine aggregate, coarse aggregate, quarry dust, fly ash and water were used for making the various concrete mixes.

For finding a suitable mix proportion for making prestressed hollow slab, five different combinations were checked. For getting good surface finish, fly ash and quarry dusts were used along with fine aggregates. Instead of 20mm aggregate 12mm and 6mm metals has used for getting good surface finish. Mix proportions were selected to get a compressive strength of 40 N/mm^2 and good surface finish. Details of different mix proportions are shown in Table 1.

3.1. Test on Hardened Concrete

Standard moulds were used for casting 150 mm cube specimen. A total of fifteen specimens were cast. In the present study, the compression test was carried out on cubical specimen of size 150 mm × 150 mm in a compression testing machine of capacity 2000 kN, at a loading rate of 14 N/mm^2 per minute. The test was done for all the five concrete mixes for determining the 7th day, 14th day as well as the 28th day compressive strength. The maximum load applied to the specimen was noted and compressive strength was calculated by dividing the maximum load by the cross sectional area of the specimen.

Table 1 Various mix proportions

MIX	MATERIALS (Kg)						
	CEMENT	COARSE AGGREGATE		FINE AGGREGATE			WATER
		12mm	6mm	M Sand	Fly Ash	Quarry Dust	
1	478.95	781.27	334.83	547.25		136.81	191
2	478.95	781.27	334.83	547.25	136.81		191
3	478.95	837.08	279.02	547.25		136.81	191
4	478.95	837.08	279.02	547.25	136.81		191
5	478.95	837.08	279.02	478.842	102.6	102.6	191

4. DESIGN AND CASTING

4.1. Design of Prestressed Hollow Slab

The slab was designed as a partially prestressed slab as per IS: 1343 (2012) stipulations. The slab having a length of 4000mm, width of 600mm and 120 mm depth has taken for study. Effective cover provided was 20mm. It was designed as a type 2 member, such that no tensile stress was permitted at transfer stage and visible cracks were not allowed. Prestressing force was provided to counteract the dead load and floor finish of 1kN/m^2. And for a live load of 2kN/m^2, the section was designed as a one way slab. Twenty one numbers of 4mm diameter tendons having an ultimate tensile strength of 1500N/mm^2 were provided to take a

prestressing force of 275kN at an eccentricity of20mm and each one of these prestressing tendons required a pull of 13.13kN. Three numbers of 8mm diameter HYSD bars grade 415 were provided for taking live load. The details of providing reinforcement and tendons are shown in Fig. 1.

4.2. Design of Mould

The mould has been designed as per IS: 800 (2007) stipulations. It was designed as two separate moulds, one as loading frame and other as casting mould. In loading frame, ISMB 250 section was used at longer side and two numbers of ISMC 200 were used at shorter spans. As such, we can easily place the prestressing tendons in between the two C sections. The plan of the loading frame and casting mould are shown in Fig. 2.

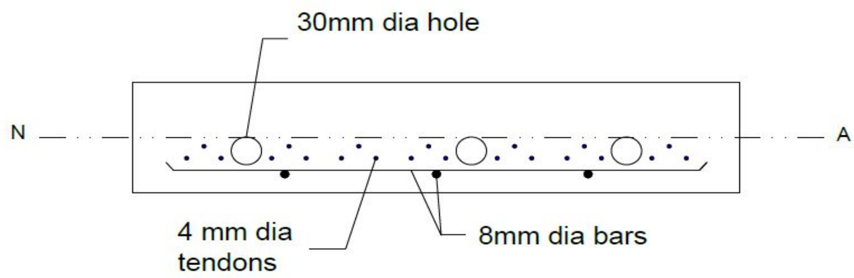

Figure 1 Reinforcement details of prestressed hollow slab

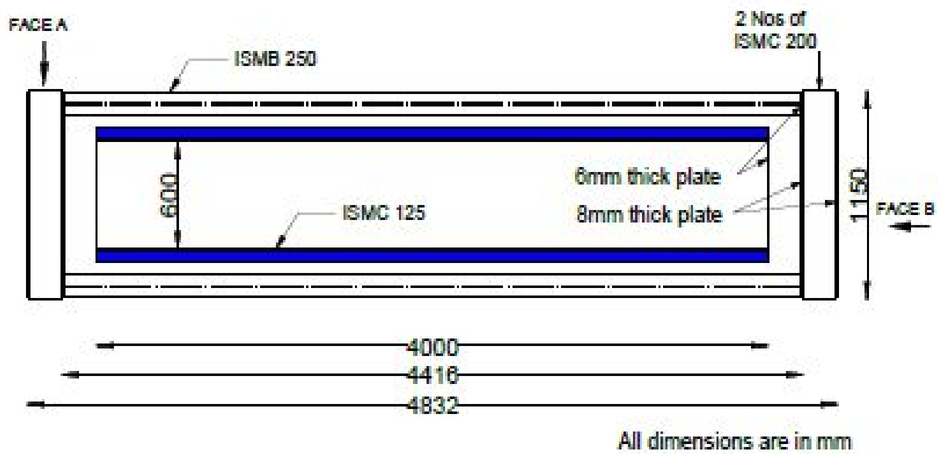

Figure 2 Plan of the mould

4.3. Design of RCC Slab

The **s**lab was designed as one way slab as per IS: 456 (2000) stipulations. The slab having a length of 4000mm, width of 600mm and 150 mm depth has taken for this study. Effective cover provided was 20mm. The slab was designed to take the dead load, floor finish load of $1kN/m^2$ and a live load of $2kN/m^2$. Area of steel provided was 410 mm^2. Five numbers of 8mm diameter HYSD bars grade 415 was provided at a spacing of 120mm center to center. The theoretical deflection of the slab was 4.99mm.The design steps are shown in Appendix B. The details of providing reinforcement are shown in Fig. 3.

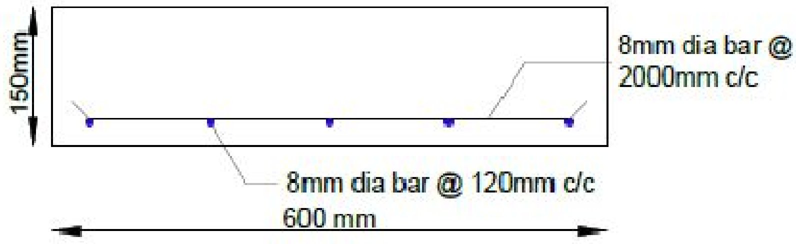

Figure 3 Reinforcement details of RCC slab

4.4. Preparation of Prestressing Mould

Loading frame and casting mould were prepared using structural steel members. Inner dimensions of casting mould have the same dimension as that of casting slab. Twenty one holes were introduced in the mould for inserting the tendons easily into the slab. In loading frame, ISMB 250 section was used at longer side and two numbers of ISMC 200 were used at shorter spans.

The loading frame was placed in the level ground. After tightening all the nuts and bolts in the loading frame, the casting mould was kept inside the loading frame. The mould was placed in correct position in such a way that the tendon holes of mould coincide with the holes in the loading frame. On either side proper gap was provided between the loading frame and mould to cut the tendons in the transfer stage. The sides of the mould were oiled and reinforcement was placed inside the mould by ensuring correct cover. Fig. 4 shows the prestressing loading frame and mould after applying prestressing forces to each tendon.

Figure 4 Prestressing mould

4.5. Prestressing and Casting

Gifford Udall system was used for prestressing. At first, the reinforcements were positioned inside the mould by using 20mm cover block. Pretensioning method has adopted for prestressing the hollow slab. In pretensioning, the tension is applied to the tendons before casting of the concrete. For doing the same, 4mm diameter tendons were inserted through the holes in one side of the mould and that was anchored using cone and wedges. The wires were drawn through holes on the other end and that too were anchored by cone and wedges. The remaining portions of the tendons were allowed to pass through the piston portion of prestressing equipment. Then the projecting portion of the tendons from the piston should

also anchor with cone and wedge. A prestressing force of 13.13kN was applied to each tendon in diagonal wise by a hydraulic jack and hence a total force of 275kN was introduced to the tendons. The prestressing was carried out with a prestressing equipment of 500kN capacity. The prestressing equipment and prestressing process are shown in Fig. 5. The casting of prestressed hollow slab and prepared specimen are shown in Fig. 6. For each concrete mix, three cubes were cast for studying its mechanical properties.

4.6. Transfer of Prestress

The curing was started after 24 hours of casting, by making small ponds using low strength mortar. This need to be done at regular intervals in order to keep the slab in moist condition for 28 days. In this study prestress was transferred to the slab on the fourth day after casting. This was done by cutting the tendons on both sides of the slab. After this process the slab was removed from the mould and the curing was continued.

Figure 5 Applying prestressing forces to tendons and prestressing equipment

Figure 6 Casting of prestressed hollow slab

4.7. Transfer of Prestress

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5. TESTING OF PRESTRESSED HOLLOW SLAB

The objective of the study is to check whether the prestressed hollow slab can withstand a uniformly distributed design load within the permissible deflection limit. The entire testing was conducted outdoor due to the length of the slab. A simply supported setup was arranged outside the lab using two ISMB 250 sections.

The figurative representation of the test setup is shown in Fig. 7. The slab was lifted using a mechanical crane and was placed over the ISMB 250 sections. The I sections was placed in such a manner that the support width is 200 mm similar to that of a conventional wall thickness. One set of LVDT was placed over the slab to measure the deflection of the slab. This was positioned at the centre of the slab. Finally sand bags weighing 50kg were placed over the slab one by one as shown in Fig. 8. While placing each sand bag, the corresponding deflection was recorded using LVDT.

For observing more deflection variations additional loads were placed over the slab using concrete blocks and man weight as shown in Fig. 7. The corresponding deflection values were also recorded using the LVDT.

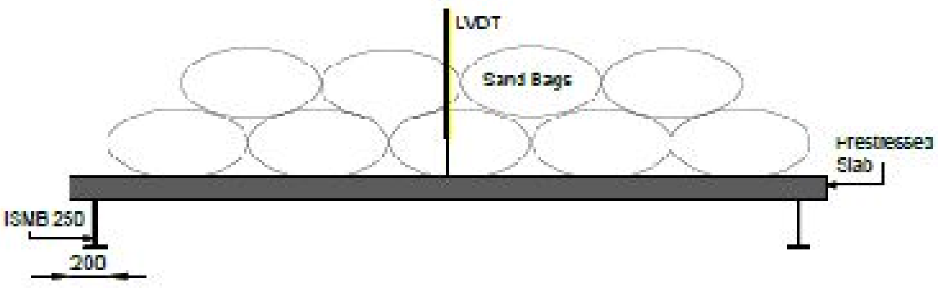

Figure 7 Experiment test setup

Figure 8 Experiment test setup of prestressed hollow slab

6. RESULTS

The flexural behaviour of prestressed hollow slab was studied experimentally and analytically. Flexural behaviour of RCC slab was also studied analytically. The test results obtained were tabulated and a detailed analysis and discussion on the results are presented in this chapter.

6.1. Load v/s Deflection

A maximum load of 1802 kg was applied on prestressed hollow slab and the corresponding deflection at the centre was 6.99 mm. From the experimental study it was found that, the slab can carry a load of about four times that of design load. The applied loads and corresponding deflection values are shown in Table 2.

Table 2 Load v/s Deflection table

LOAD(kg)	DEFLECTION(mm)
0	0
50	0.07
100	0.16
150	0.30
200	0.41
250	0.56
300	0.71
350	0.96
400	1.15
430	1.25
460	1.43
490	1.55
542	1.63
594	1.74
694	2.07
769	2.36
915	2.84
996	3.02
1065	3.41
1140	3.60
1215	3.96
1302	4.09
1384	4.32
1451	4.66
1526	5.02
1614	5.78
1715	6.04
1802	6.99

From the above data a load verses deflection graph has also plotted as shown in Fig. 9. From the graph it is clear that the load verses deflection graph is almost linear up to 12kN which is around three times higher than the design live load. Small variation in the linearity has occurred after a live load of 12kN. This difference may be due to the prestressing losses which might occur in the casting processes and errors in distributing load over the slab.

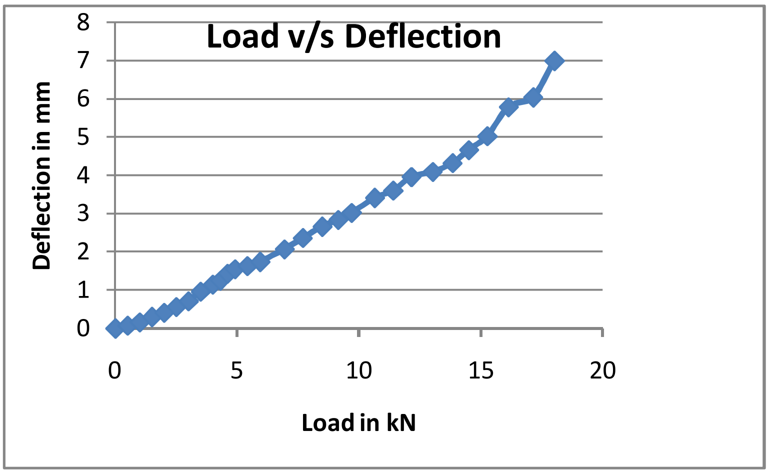

Figure 9 Load v/s Deflection graph

6.2. Comparison of Deflection

Table 3 Comparison of deflection values

	DEFLECTION VALUES	
	THEORETICAL	EXPERIMENTAL
PRESTRESSED HOLLOW SLAB	1.04 mm	1.15 mm
RCC SLAB	2.55 mm	-

Table 3 shows the deflection value of prestressed hollow slab and RCC slab for a design live load of 2kN/m^2. The deflection values were calculated using theoretical, analytical and experimental methods.

6.3. Deflection for a Maximum Live Load of 7.33 kN/m^2

The deflection value of prestressed hollow slab for a live load of 7.33 kN/m^2 is shown in Table 4.

Table 4 Comparison of deflection values of prestressed hollow slab

Theoretical deflection for a LL of 7.33 kN/m^2	5.07 mm
Experimental deflection for a LL of 7.33 kN/m^2	m

7. CONCLUSION

Experimental investigation on the developed prestressed hollow slab was carried out and it has found that at design live load of 2kN/m^2, the variation in experimental deflection was found to be 14% greater than the theoretical deflection. And at maximum applied live load of 7.33kN/m^2, the variation in experimental deflection was found to be 29% greater than the theoretical deflection. For the same load, the depth requirement for prestressed hollow slab was found to be less compared to conventional RCC slab: The weight of prestressed hollow slab was 21% less than RCC slab and this reduction in dead load reduces the seismic load acting on the structure.

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